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An Alternate Approach to Traffic Analysis for Residential Buildings

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Key Words: Traffic analysis, residential, interval, waiting time, performance requirements, simulation

ABSTRACT

Residential elevators are traditionally required to handle 5% to 8% two-way traffic between the Lobby and the residential levels with an Interval in the range of 40 to 80 seconds. This traffic situation is most accurately analyzed with simulation, rather than the simplified calculations of Round Trip Time and Interval. However, because the long standing industry definition of Interval involves only events where cars leave the home floor in the up direction, a narrow focus on Interval can often give an unrealistic picture of elevator performance. This is especially true when buildings have multiple entry levels such as parking floors. This paper presents an alternate method for estimating Interval and makes the case for using Average Passenger Waiting Time in place of Interval for evaluating performance.

1. INTRODUCTION

There have been an increasing number of high rise residential buildings constructed in the U.S. and Canada in the last few years. Many of these buildings are located in downtown areas and have 25 or more levels of true luxury condominiums. Whereas a comparable 25-story office building might have 10 or more elevators, it is not uncommon for the residential building to have as few as two or three elevators. Furthermore, unless the residential building is very tall or the floor population is very heavy, it is most common for all elevators to serve all levels. The reason for the difference in elevator configurations in a residential building, of course, is the lighter traffic, smaller population per floor, and the performance requirements themselves.

Many architects and developers have recognized the value of proper elevatoring for their projects and have turned to consultants and/or elevator suppliers for help in determining the best elevator configuration. With the increasingly common availability of comprehensive computer software for traffic analysis, the task of exploring the performance of alternative elevator configurations is made easier, quicker, more accurate, and more complete than with previous manual methods. However, the use of computer simulation software by the inexperienced analyst can at best be tricky and at worst lead to inaccurate conclusions.

This paper proposes that computer simulation software should be used to determine the performance of a proposed group of residential elevators as they respond to the required two-way traffic pattern. Simply stated, simulation that focuses on passenger waiting time provides the most comprehensive and realistic method for analysis, in contrast to the older calculation procedure for Round Trip Time, Interval and Handling Capacity. Because the long standing industry definition of Interval involves only events where lifts leave the home floor in the up direction, a narrow focus on Interval can often give an unrealistic picture of elevator performance. This is especially true when buildings have multiple entry levels such as parking garage floors or when idle elevators are allowed to sit idle at floors above the main lobby.

We will propose an alternate method for evaluating the performance of residential elevators and make the case that the best measure of performance is Average Passenger Waiting Time, rather than Interval as reported from the simulation software.

2. PERFORMANCE REQUIREMENTS FOR RESIDENTIAL ELEVATORS

Available documents relating to performance requirements for residential elevators agree that planning should focus on two-way traffic during the late afternoon when traffic volume is heaviest. During this time, residents are returning to the building, perhaps from work or other outside activities. At the same time, residents who have already returned are leaving the building for dinner, exercise, etc. The elevators transport residents upwards from the main lobby to their floor of residence and then stop in the downwards direction to carry other residents back to the main lobby.

Requirements on elevator performance specify that the elevators must be able to handle a certain peak volume of two-way traffic (called Handling Capacity) while maintaining a certain Interval. While the actual parameter values for performance requirements are a matter of opinion, the table below is representative of such requirements which appear in public literature, various elevator supplier's internal documents, and consultant's specification documents.

Table 1
Common Requirements for Residential Elevators

	Luxury Residential	Normal Residential	Economy
Handling Capacity (% of population per 5-minutes)	**7% - 8%**	6% - 7%	5% - 6%
Interval	**< 50 secs**	< 60 secs	< 70 secs

To fully specify the traffic volume in terms of the number of passengers per 5-minutes, it remains to provide an estimate of the building's population. Population is most often estimated as a function of the number of bedrooms per the following table.

Table 2
Number of People <u>per Unit</u> by number of bedrooms and type of building

Type of Residential Unit	**Luxury Residential**	Normal Residential	Economy
Studio	**1.0**	1.5	2.0
One Bedroom	**1.5**	1.8	2.0
Two Bedroom	**2.0**	3.0	4.0
Three Bedroom	**3.0**	4.0	6.0

Again, this table is representative of various sets of guidelines, and specific values would be a matter of opinion.

These specifications fall short in two important areas. First, they do not specify how the Interval is to be determined. Second, there is no discussion of the now-common feature of automobile parking levels integral to the building. Internal parking presents a significant deviation from the implicit assumption of the traditional calculation method that residents enter and exit the building by way of a single entrance level, namely the main lobby.

3. EXAMPLE 25-STORY RESIDENTIAL BUILDING

Consider a proposed 25-story true luxury residential building for which the estimated population per level is small, varying from 4 persons to 12 as shown on Figure 1. The total population of the building is estimated at 236 residents.

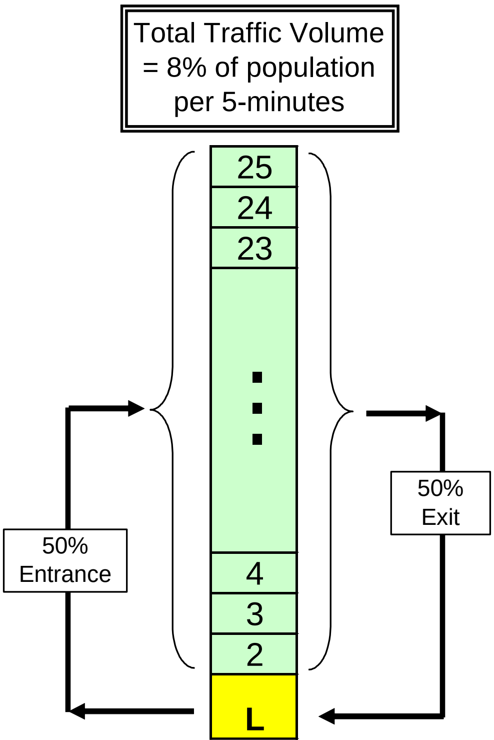
An elevator configuration comprising three cars is under serious consideration. It becomes the task of the elevator professional to evaluate the configuration and compare the predicted performance to industry standards. As indicated in Table 1, elevators in this luxury building must be able to handle a peak 5-minute traffic volume of 8% of the population and provide an Interval of 50 seconds or less.

We used the simulation feature of the Elevate traffic analysis software to evaluate the performance of the proposed elevator configuration in this building.

A traffic pattern (shown in Figure 2) was established in which it was estimated that the heavy two-way traffic referenced in the requirements occurred over a 20 minute time period. This type of traffic reflects the typical peak late afternoon traffic period referenced in the requirements. Per the requirements, during this period some 8% of the population calls for elevator service in each five minute period. For this building, this amounts to 19 passengers ($0.08 \times 236 = 18.88$) per five minutes. Some 50% of the passengers are assumed to be calling for elevator service to travel upward from the Lobby to their floor. At the same time, the other 50% of passengers are already on their residential floor and demand elevator transportation to carry them downward to the Lobby.

Floor	Pop
25	4
24	4
23	4
22	8
21	8
20	8
19	8
18	8
17	8
16	12
15	12
14	12
13	12
12	12
11	12
10	12
9	12
8	12
7	12
6	12
5	12
4	12
3	12
2	8
L	
	236

Figure 1. Example Residential Building



Important input parameters for Elevate simulation were established as follows:

- Number of Elevators: 3 geared lifts
- Capacity: 3000 lbs. (approx 1350 kg)
- Speed: 450 fpm (approx. 2.3 m/s)
- Acceleration 3.0 ft/sec^2
- Jerk 4.0 ft/sec^3
- Maximum Car Loading 65% of capacity (approx 11 passengers)
- Door Open Time 2.0 secs
- Door Close Time 3.0 secs
- Loading Time 1.2 sec/passenger
- Unloading Time 1.0 sec/passenger
- Typical floor height 10’8” (approx 3.25m)
- Total travel approx 267’6” (approx 81.5m)

Elevate simulation experiments were run for several 20-minute periods and the following results were observed. Average Passenger Waiting Time was 11.7 seconds, and the Average Interval was 43 seconds. These results are shown in graphical form in Figure 3.

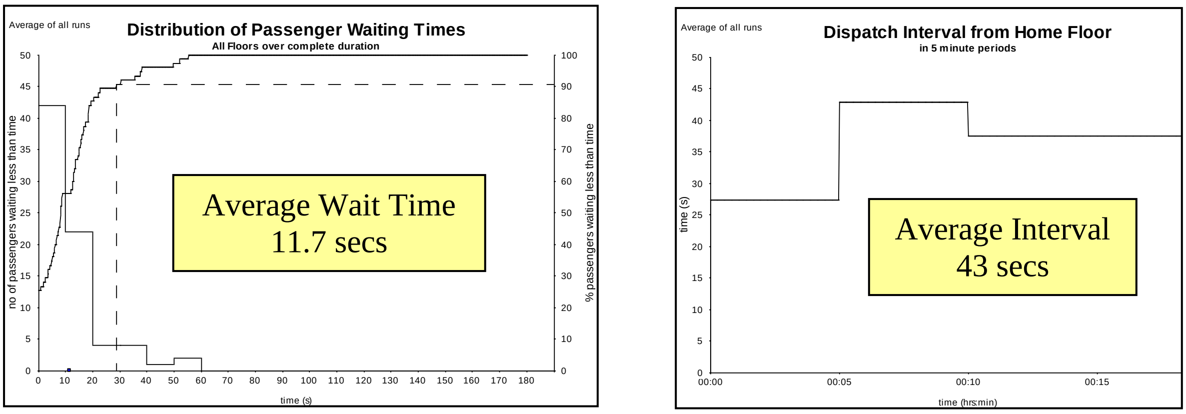


Figure 3. Simulation Results for Example Building

Because the resulting Interval of 43 seconds falls within the satisfactory range of the requirements for a luxury building, we can conclude that a group of three 3000# 450 fpm geared elevators will meet the requirements. It is also noted that the waiting time is exceptionally short.

4. MODIFIED BUILDING DESIGN WITH ABOVE GROUND PARKING

With a single entrance, the example in Section 3 is clearly the simplest of traffic scenarios. It is not totally out of the question to expect that a luxury residential building will have parking garage levels within the structure. Therefore, we took the 25-story example and added three levels of above ground parking. We assume that the same requirements would apply … peak two-way traffic at 8% with half of the traffic returning to the building and the other half leaving the building. The important difference, however, is that now there are four different levels of entrance and exit: main Lobby and parking levels P-A, P-B, and P-C. It is now incumbent on us to determine the distribution of traffic to and from each level. With reference to Figure 4, we assume somewhat arbitrarily that entrance traffic is divided equally amongst the four levels. In contrast, the exit traffic is assumed to be different where only 10% of exiting passengers use the main Lobby level. This reflects the situation where many fewer people leave the building by walking out on foot from the main Lobby than by automobile from the parking levels.

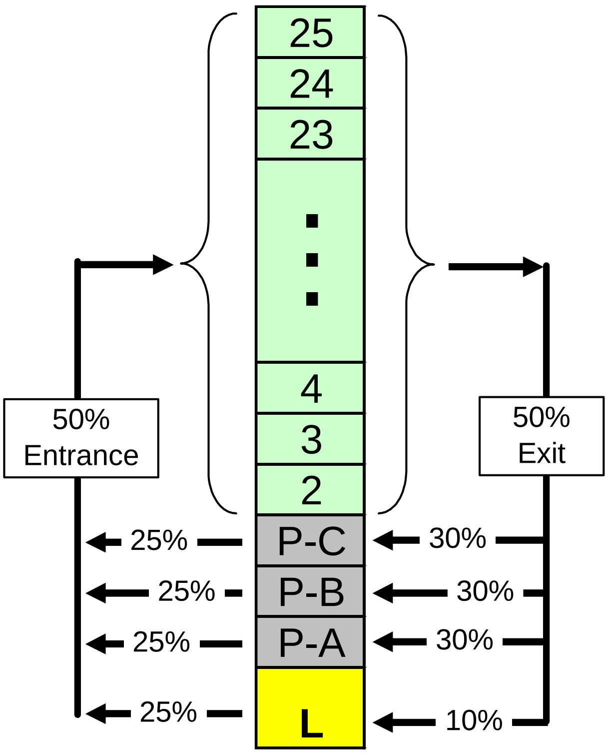


Figure 4. Traffic Pattern for Above Ground Parking

With the same Elevate input parameters in place, we ran simulations using the new traffic pattern with above ground parking. For this case, Elevate reports an Average Passenger Waiting Time of 18.9 seconds and an Interval of 115 seconds.

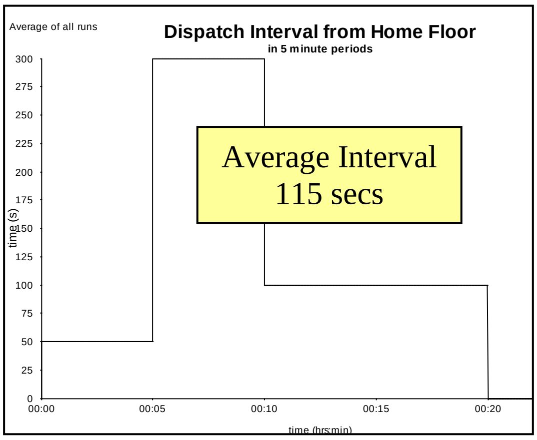


Figure 5. Interval for Above Ground Parking

These results are somewhat confusing. The passenger waiting time seems very tolerable, but the Interval is very far outside the acceptable range of 50 seconds or less.

To explain this dichotomy, we begin by reviewing the relationship between Interval and Average Passenger Waiting Time. From fundamental principles of elevator traffic analysis, the relationship between Average Passenger Waiting Time (AWT) and Interval (INT) under ideal building conditions is

$$AWT = 0.50 \times INT$$

This result is based on ideal conditions where all cars are equally spaced apart in the building. Experienced traffic analysts and consultants understand that cars often bunch together, so that the AWT can be as high as 60% of the Interval. *[Note: Some consultants would say that AWT can be even as high as 75% of the Interval. However, for this discussion, we will use 60%.]* Thus, we can say that the AWT will lie in the range of 50% to 60% of the Interval:

$$(0.50 \times INT) \leq AWT \leq (0.60 \times INT)$$

Now if the required Interval is 50 seconds as it is for a luxury residential building, we can insert INT=50 into the above set of inequalities and obtain the implied requirement that the AWT must be in the range of 25 to 30 seconds. For this case of a residential building with above ground parking where the AWT was determined to be 18.9 seconds, the performance is even better than the required 25 to 30 seconds. But this still does not explain why Elevate's reported value for Interval is still so high.

The explanation must refer to the fundamental definition of Interval, which in simple terms is the "interval of time between departures of elevators from the main lobby level in the up direction." This definition, of course, has an implied reference to the Up Peak traffic scenario in an office building where cars carry office workers from the Lobby to their floors in the morning. An Interval of 30 seconds means that a car will be departing every 30 seconds or so, and thus passengers will wait about 15 seconds on average.

The Elevate software has been designed to "log" departures of cars from the main Lobby level and then calculate the average time between such events. The problem can readily be seen with reference to Figure 6, which shows the positions of Car 2 during the 20-minute simulation. This graph shows Car 2 leaving the Lobby at 2 minutes 11 seconds (see left-most arrow), traveling upwards to Level 14, returning back down to a parking level, traveling upwards to Level 16, etc. Car 2 makes a total of six up and down trips before ever returning to the Lobby (right-most arrow), consuming a total time of 00:09:39. The fact that this very large time value is included in Elevate's Interval computation explains why the overall average Interval (115 seconds) is so long.

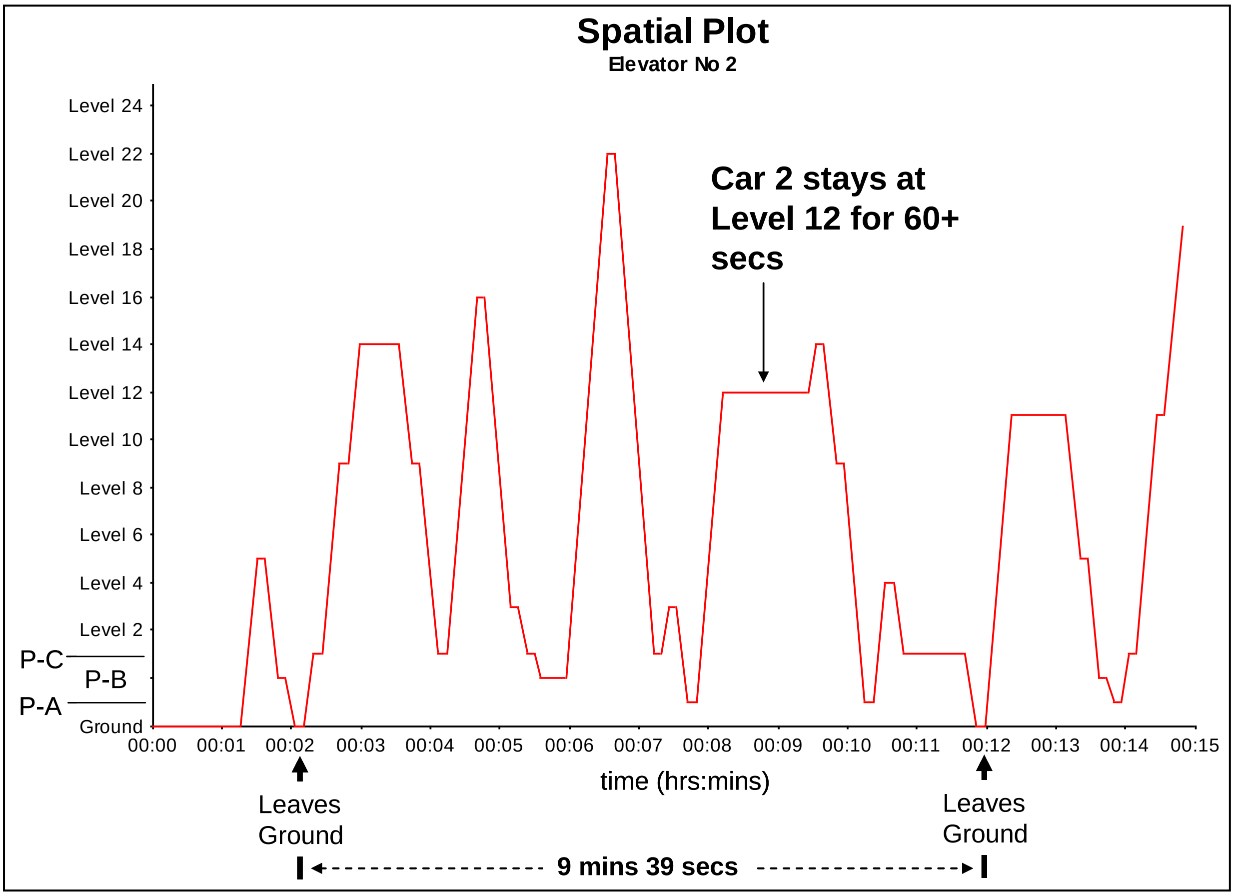


Figure 6. Spatial Plot of Car 2 Bypassing Lobby for Case of Above Ground Parking

We can therefore safely conclude that even though the Interval is far outside the acceptable range, the residents of this building are still receiving very good elevator service as evidenced by the AWT of 18.9 seconds.

5. MODIFIED BUILDING DESIGN WITH BELOW GROUND PARKING

The developers of this luxury residential building are also considering locating the parking levels below ground. A separate traffic analysis for this case was run with the traffic pattern as shown in Figure 7.
Simulation results for this case tell a similar story to the case of above ground parking. The reported AWT was 18.3 seconds, and the Interval was 136 seconds. As before, the extra long interval is explained by the fact that the cars do not make regular stops at the Lobby level where “interval events” are logged. Figure 8 shows that Car 3 left the Lobby in the up direction at time 00:04:28. The next time that it stopped at the Lobby and traveled upward was at 00:15:44. This represents a time between “interval events” of more than 11 minutes.

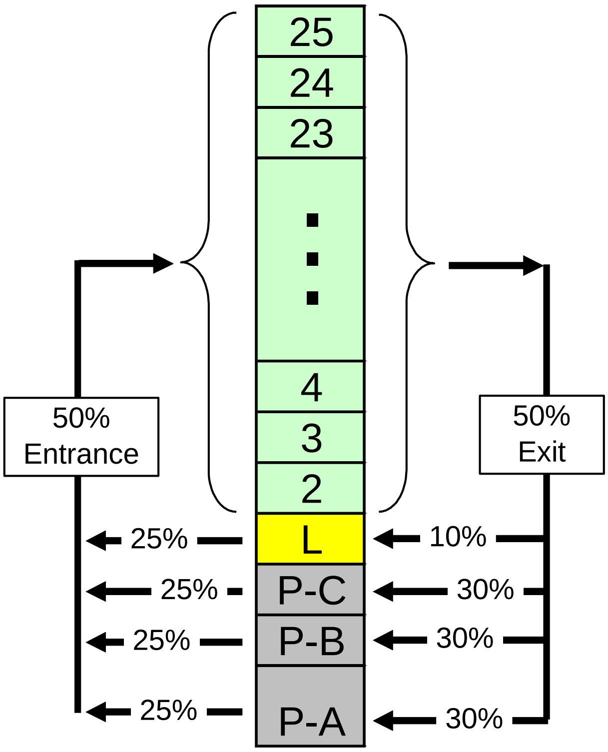


Figure 7. Traffic Pattern for Below Ground Parking

It is interesting to note that during that 11+ minute period, Car 3 passed the Lobby level going upwards a total of five times. These times are noted by the circles in Figure 8. This car could have stopped at the Lobby but did not do so because there was no demand at this level.

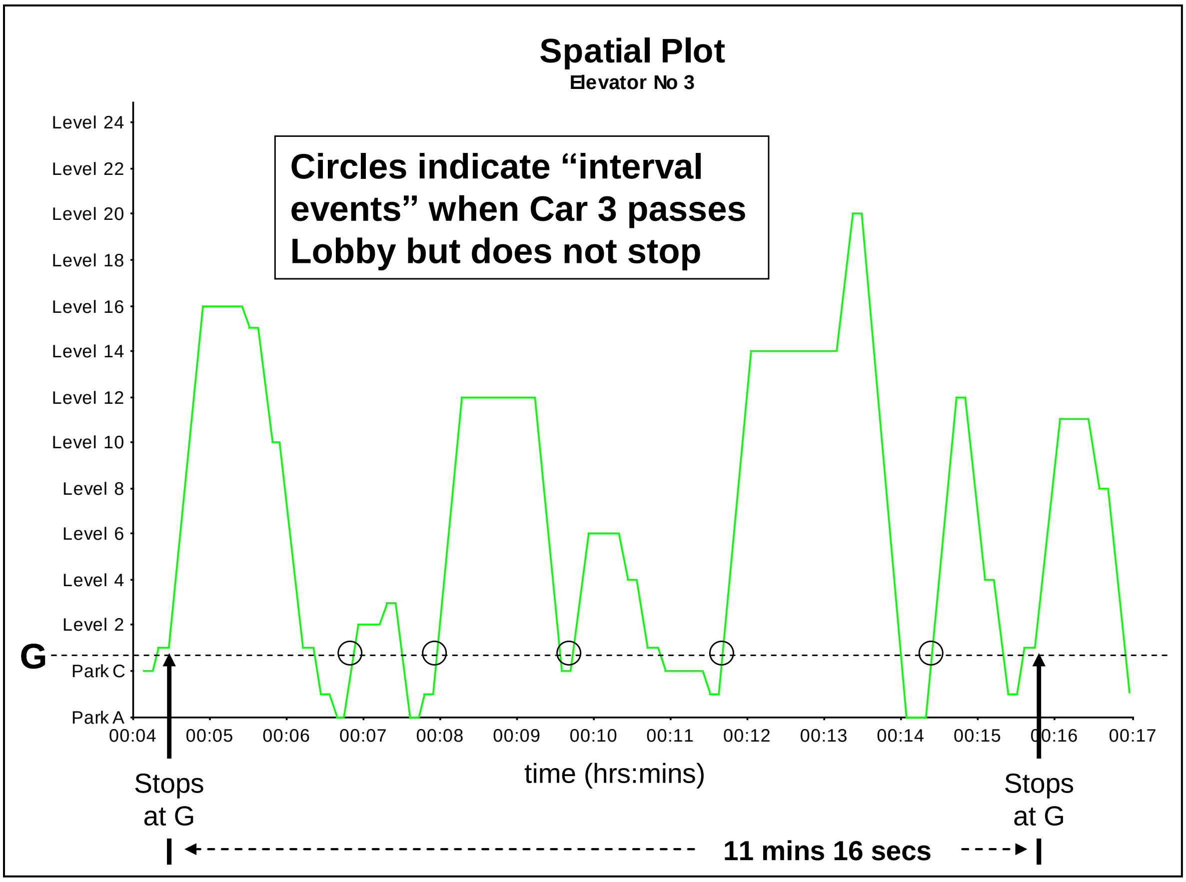


Figure 8. Spatial Plot of Car 3 Bypassing the Lobby for the Case of Below Ground Parking

Again, we can therefore safely conclude that even though the Interval is far outside the acceptable range, the residents of this building are still receiving very good elevator service as evidenced by the AWT of 18.3 seconds.

6. RECOMMENDATIONS

We have seen that for both cases of building design with internal parking levels … above ground and below ground … there is a major dichotomy in results between Interval and Average Passenger Waiting Time. If we relied on the Interval alone as reported by Elevate, the proposed configuration would be immediately rejected as unacceptable. Yet at the same time, the Average Passenger Waiting Time is well within the acceptable range.

One solution to this dilemma is to somehow change the definition of Interval for these situations and ask the developer of Elevate or other simulation software to report this new value. This would be most easily accomplished in the case of underground parking where the nature of traffic results in downward traveling cars always reaching the main Lobby or below. Then we could invent something called an “interval event” which would comprise two types of situations: (1) when a car stops at the Lobby and then moves upward, and (2) when a car moves upward from a parking level and passes the Lobby without stopping. The first situation is the traditional event that is currently accounted for in Elevate. The second situation captures the fact that “the car could have stopped at the lobby if there was a need for it to do so.” These second type of interval events are shown as circles in Figure 8 above. However, this solution still would not adequately account for cars parking for periods of time above the Lobby as they often do during times of light traffic that is typical of residential buildings.

The most practical solution to this dilemma is to include Average Passenger Waiting Time to the requirements. We would use the commonly accepted relationship between Interval and Average Passenger Waiting Time to add a line to the table of requirements. As shown in the equations of Section 4, if the required Interval was 50 seconds or less, this would be equivalent to requiring the Average Passenger Waiting Time to be in the range of 25 to 30 seconds.

Table 3
New Table of Requirements Including Average Passenger Waiting Time

	Luxury Residential	Normal Residential	Economy
Handling Capacity (% of population per 5-minutes)	**7% - 8%**	6% - 7%	5% - 6%
Interval	**< 50 secs**	< 60 secs	< 70 secs
New Average Passenger Waiting Time	**25-30 secs**	30-36 secs	35-42 secs

With this approach, the traffic analyst would use simulation to determine the Average Passenger Waiting Time for the required two-way traffic pattern and simply compare the reported value of Average Passenger Waiting Time to the limits in Table 3. The implication of this recommendation is that for the case of residential buildings, the traditional concept of Interval is of little or no interest. We should focus on what is important to the passenger, which is Average Passenger Waiting Time.

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BIOGRAPHICAL DETAILS

Bruce Powell is President of the Bruce Powell Company, which provides specialized consulting in elevator traffic analysis. Dr. Powell earned a B.S. in Mathematics from Denison University and an M.S. and Ph.D. in Operations Research from Case Western Reserve University. He has 40 years experience in the elevator industry, having worked for both Westinghouse and Otis prior to forming his own company in 2002. He has published widely, including a number of papers in the IAEE's Elevator Technology series, has 34 issued U.S. patents, and has had his work featured in media including CNN, the Wall Street Journal, and the New York Times. He resides with his wife in Canton, Connecticut, and has three adult daughters and 11 grandchildren.